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I HEREBY CERTIFY that annexed hereto is a true copy of documents filed in connection with the following patent application:

Application No.	S990061
Date of Filing	29 January, 1999
Applicant	SUPARULES LIMITED, an Irish Company of 9 Technological Park, Castletroy, Limerick, Ireland.

Dated this 8th day of February, 2000.

An officer authorised by the
Controller of Patents, Designs and Trademarks.

S990061

FORM NO. 1

REQUEST FOR THE GRANT OF A PATENT
PATENTS ACT, 1992

The Applicant named herein hereby request

__ the grant of a patent under Part II of the Act

x the grant of a short-term patent under Part III of the Act

on the basis of the information furnished hereunder.

1. **APPLICANT**

Name	**SUPARULES LIMITED**
Address	**9 Technological Park, Castletroy, Limerick, Ireland**
Description/Nationality	**An Irish Company**

2. **TITLE OF INVENTION**

"Current Measuring Device"

3. **DECLARATION OF PRIORITY ON BASIS OF PREVIOUSLY FILED APPLICATION FOR SAME INVENTION (SECTIONS 25 & 26)**

Previous filing date	Country in or for which filed	Filing No.

4. **IDENTIFICATION OF INVENTOR(S)**
Name(s) of person(s) believed by Applicant(s) to be the inventor(s)
1. Thomas Sorenson

Address
1. Darien, Annacotty, County Limerick, Ireland

5. **STATEMENT OF RIGHT TO BE GRANTED A PATENT (SECTION 17(2)(B))**

By virtue of a Deed of Assignment dated January 29, 1999.

Contd./...

6. **ITEMS ACCOMPANYING THIS REQUEST - TICK AS APPROPRIATE**

(i) X prescribed filing fee (£50.00)

(ii) __ specification containing a description and claims

X specification containing a description only

X Drawings referred to in description or claims

(iii) __ An abstract

(iv) __ Copy of previous application(s) whose priority is claimed

(v) __ Translation of previous application whose priority is claimed

(vi) __ Authorisation of Agent (this may be given at 8 below if this Request is signed by the Applicant(s))

7. **DIVISIONAL APPLICATION**

The following information is applicable to the present application which is made under Section 24

Earlier Application No:
Filing Date:

8. **AGENT**

The following is authorised to act as agent in all proceedings connected with the obtaining of a Patent to which this request relates and in relation to any patent granted -

Name	**Address**
F. R. KELLY & CO.	at their address as recorded for the time being in the Register of Patent Agents

9. **ADDRESS FOR SERVICE (IF DIFFERENT FROM THAT AT 8)**

SUPARULES LIMITED
F. R. KELLY & CO.

By: ____________________
EXECUTIVE

Date: January 29, 1999

APPLICATION No. S990061

Current Measuring Device.

This invention relates to an apparatus for measuring alternating current flowing in an electric conductor, for example an a.c. mains wire.

Ampere's law states that the integral of the magnetic field around a closed loop surrounding a current source is equal to the current enclosed.

This is the principle used in conventional one wire current probes and the method of measurement is shown in Figure 1.

A loop 10 of magnetic material surrounds a current carrying conductor 12 and a coil 14 comprising a large number of turns of wire is wound on the magnetic material 10.

This type of probe has two major advantages:

1. In a well designed probe the voltage or current induced in the coil 14 is not dependent on the position of the source current (conductor 12) within the cross section surrounded by the closed magnetic core 10.

2. The ratio of pickup voltage or current from a current source 12 within the closed magnetic ring core 10, compared to the pickup from the same source when it is located outside the closed magnetic ring core is very large, e.g. >1000:1.

This ensures that stray pickup from interfering current sources which may be located close to the probe but outside the magnetic ring core do not affect the measurements obtained from the required source which is located inside.

One of the disadvantages of this type of probe however is its cost. The magnetic core must be manufactured in two or more sections. This allows the closed magnetic core to be opened, permitting the insertion of the current conductor to be measured. The magnetic core is then closed again and the measurement taken. In order to make an accurate measurement the alignment of the two sections on closing is critical, as is the requirement that even a small air gap between sections on meeting is not allowed. These mechanical requirements make this probe relatively expensive.

The arrangement shown in Figure 1 may also be used if the magnetic material 10 is replaced by a non-magnetic material. This retains the two advantages of the closed magnetic core as stated above. In this case, however, for accurate measurements the turns must be wound uniformly over the whole length of the closed non-magnetic core. Also the voltage induced with this non-magnetic core material is frequency dependent and much smaller than that obtained using the magnetic core and thus requires amplification. Here again, however, the core must again be manufactured in at least two sections so that the sections may be moved apart to allow ingress of the source conductor. The alignment of these two sections when they return to the closed position around the test conductor is critical,

although a very small air gap will not cause as large an error in measurement as in the magnetic core material model.

The mechanical design and manufacture of this probe with its moving parts is nevertheless difficult and expensive.

The most cost effective probe should have no moving parts if possible. To avoid moving parts in the non magnetic core design a gap must exist both in the non magnetic core and the windings. A probe which uses this system is shown in Figure 2, and such a probe is described in US Patent No. 5,057,769. In this design a gap 17 is provided in a continuously wound non-magnetic core coil 15 to allow the insertion of the current source. In an attempt to maintain the desirable features of the continuous winding closed non-magnetic core, an effort is made to add back in the voltage component that would have been picked up by the coil turns which were removed to provide the air gap 17. In the design of Figure 2 this has been attempted by adding two individual multiturn coils 16 at either side of the gap 17. Even with the correct number of turns in these coils this is only partly successful. When a gap or gaps are inserted in a continuous closed winding the following effects (a) and (b) are observed.

Effect (a)

The voltage pickup of the probe is dependent on the location of the source conductor within the internal cross section of the coil. The closer the source current carrying conductor is to the gap or the

windings the greater the variation in pickup. As expected, the larger the gap the larger the variation in pickup levels. However this variation can be kept within acceptable limits. For example variations of less than $\pm$ 3% may be obtained with gaps of about 1.6 cm if the source current conductor is confined to a rectangular area 18 which begins a distance D (approximately 10 mm) from the centre of the gap and ends a distance C, (also approximately 10 mm), from the continuous windings.

Effect (b)

The pickup from sources in area 19 outside the core gap cross-section is no longer negligible and the pickup from an external current source increases as the gap increases. Thus interference from other current carrying conductors outside the probe but close to its surface takes place, such interference being at a maximum when external sources are located close to the top of the gap 19 rather than to the continuous winding portion of the coil 15.

This can pose a serious limitation especially when measurements are being performed in a distribution box for example, where there may be a large number of conductors carrying various currents in a confined space. The larger the current in the interfering source(s) compared to that in the conductor being measured, the greater the error that will occur in the measured current. A very important feature of the probe design is the pickup ratio or interference ratio R between the pickup from an external source 21, at a distance x from the gap, and the pickup from the same

source when it is located in the measurement area 18. This ratio R should be minimised.

For a typical well designed probe with the configuration of Figure 2, Table 1 shows the calculated value of pickup ratio R, expressed as a percentage for increasing values of x expressed in mm. The dimension of the continuous coil portion 15 of the probe are taken as 50 mm long by 31 mm wide in the calculations of Table 1. These dimension are typical for this type of probe.

R %	x mm
22	4
12	6
7	8
4	10
2.1	12
1.2	14
0.8	16
0.6	18
0.5	20
0.4	22
0.32	24
0.28	26
0.20	34

TABLE 1.

It can be seen from Table 1 that in order to maintain an error of less than 2% due to an interfering source of the same current magnitude as the source being measured, the distance x must be greater than about 12 mm. Since the minimum value of D is 10 mm in this design then the minimum spacing (x+D) between the interfering source and the source being measured must be greater than 22 mm.

It is quite possible in the case of a distribution box, for example, that the interfering source current could be a factor of ten or more larger then the current being measured. For a factor of ten difference, the distance x source must be greater than 34 mm in order to maintain a maximum error of less than 2% due to interference and thus the total separation between measured and interfering sources would have to be greater than 44 mm.

The invention aims to provide a probe which greatly reduces the interference ratio R relative to those shown in Table 1 at equivalent distances x and results in a smaller probe exhibiting less interference. The probe is most easily implemented by first connecting in series a number N of identical Rogowski coils equally spaced along the circumference of a circle as shown in Figure 3.

The spacing 20 between any pair of coils may be used to insert a current conductor to be measured. This arrangement suffers, to some extent, from the same effects (a) and (b) as the probe of Figure 2, but the error in measurement due to these effects gets smaller ~~the number N of individual coils increases.~~

As the number N of coils increases however, for a given diameter F of circle, the gap between individual coils decreases, as does the diameter of test conductor that may be inserted. Preferably, one will use the maximum number of individual coils possible that still accommodates the largest conductor diameter required in

the application. For example if the design requires a maximum source conductor diameter of 14 mm and the coils are arranged in a circle having a diameter F 42.5 mm, then the maximum number of individual coils that may be used is seven. This leaves space for individual coil widths G of 2 mm and an enclosure thickness of 1 mm. Using the design of Figure 3 with the dimensions given above the variation in reading obtained may be kept less than ± 3% if the current conductor is confined to the rectangular area 20 which is the width of the gap and stretches vertically from the dotted line located at distance D, where D=10 mms, from the circumference diametrically opposite. This performance is very similar to the probe design shown in Figure 2.

The pickup ratio R as defined above is shown in Table 2(a) for the probe of Figure 3 having a diameter F of 42.5 mm.

R %	x mm
20	4
13.3	6
8.6	8
5.6	10
3.7	12
2.54	14
1.7	16
1.2	18
0.87	20

(a) F = 42.5 mm
N = 7

R %	x mm
25.2	4
17	6
11	8
8	10
5.4	12
3.7	14
2.6	16
1.9	18
1.37	20

(b) F = 46.5 mm
N = 7

Table 2.

If Table 1 and Table 2(a) are compared it is seen that for values of x less than 6 mm, the system of Figure 3 is only marginally better than that of Figure 2. However, as x increases beyond 6 mm the system of Figure 3 can be better by as much as a factor of 2 at x=18 mm.

However the pickup ratio R is now examined for a set of identical coils, on a circle of diameter 46.5 mm. Table 2(b) displays the pickup ratio R for this arrangement of seven coils as a function of x. The distance x in this case is measured from the circumference of the larger circle.

If both sets of seven coils each are present with their diameters differing by 4 mm then an interfering source at a distance x from the circumference of the inner circle would be a distance (x-2) mm from the outer circumference.

If the ratio R picked up by the inner set at a distance x, as shown in Table 2(a), is compared with that picked up from the same interference location by the outer set, at a distance x-2, as shown in Table 2(b), it is observed that they differ in level by a factor of 2 approximately, with the outer set picking up twice the interference level of the inner set approximately. For example, a source at x=10 mm from the inner coils will exhibit a pickup ratio R=5.6% in the inner coil set. The same source is 8 mm from the outer coils, in which a pickup ratio of R=11% is generated.

This factor 2 remains almost constant for different values of x. It is therefore possible, irrespective of the distance x, to cancel out a large proportion of the interference by subtracting approximately half the voltage picked up by the outer set from that picked up by the inner set. The factor of 0.5 is approximately the correct factor to use for these two particular coil set diameters each comprising seven identical coils.

For greater differences between the inner and outer coil set diameters there is an increase in the factor by which the interference pickup from the outer set is greater than that of the inner set. To compensate, therefore, one must subtract a smaller amount of the outer set pickup from that of the inner set in order to minimise interference. Best cancellation of interference at all distances x is obtained by minimising the difference between the diameters of both sets of coils that are used. Preferably the individual coil diameters (dimension "T" in Fig. 3) are reduced to assist in this regard.

The configuration of this minimum interference probe is shown in Figure 4 together with a possible front end amplifier 23. The factor of pickup voltage from the outer set that is subtracted from the voltage pickup of the inner set is directly proportional to the ratio of resistor values R1/R2.

Table 3 shows the interference ratio R as a function of x for the coil arrangement of Figure 4. In this table x is measured as the distance outwards from a point midway between the inner and outer circumferences. The

results shown are for an inner diameter F1=42.5 mm and an outer diameter F2 = 47.5 mm. R1 is chosen to be 0.52 R2 in this design so that the effective input signal is the voltage pickup from the inner set minus 0.52 times the pickup from the outer set.

If one compares the values of pickup ratio R of Table 3 to those of Table 1 (comparing the configuration of Figure 4 with that of Figure 2) it is seen that the interference of this new probe is far less than that of the old probe at any distance x. In fact the rejection is a minimum factor of 3.7 lower at x = 4 mm and increases to a factor of 33 lower at x = 20 mm.

The configuration of Figure 4 thus shows significant advantages over that of the known configuration shown in Figure 2 allowing the use of smaller probes with less interferences.

R %	X mm
6	4
2.4	6
0.95	8
0.41	10
0.18	12
0.08	14
0.04	16
0.024	18
0.15	20

TABLE 3

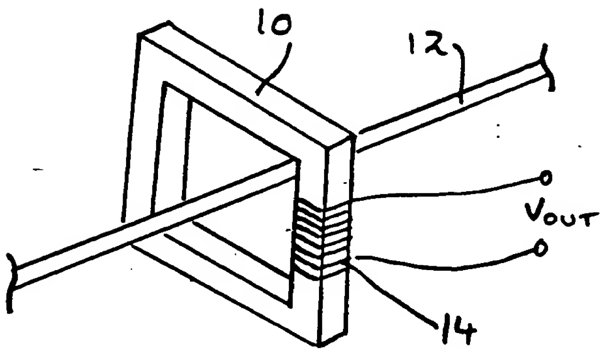

FIG. 1

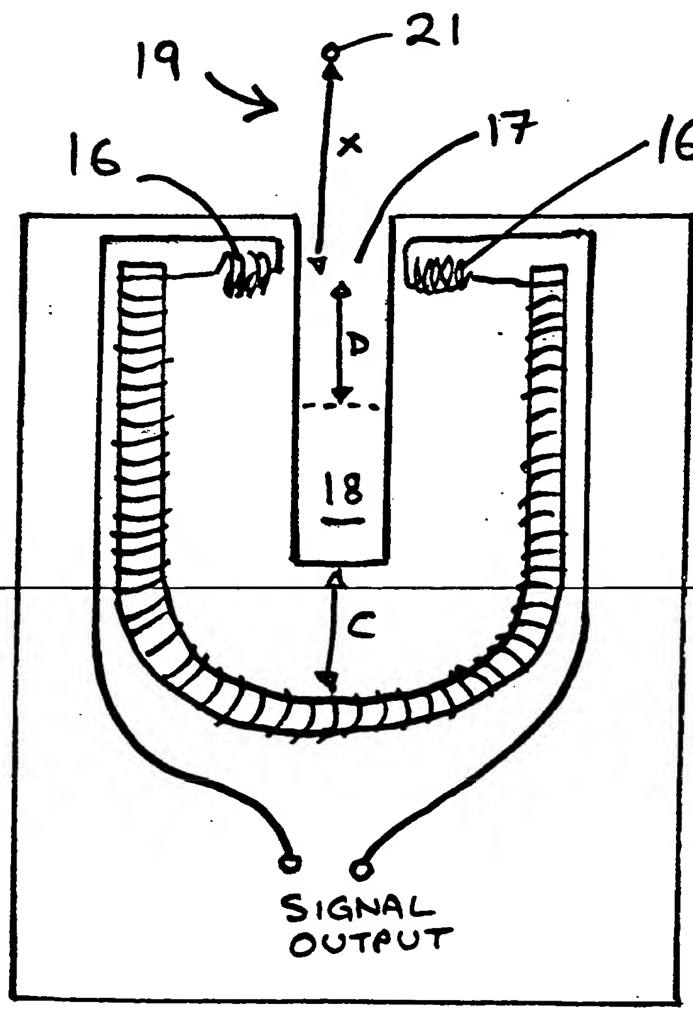

FIG. 2

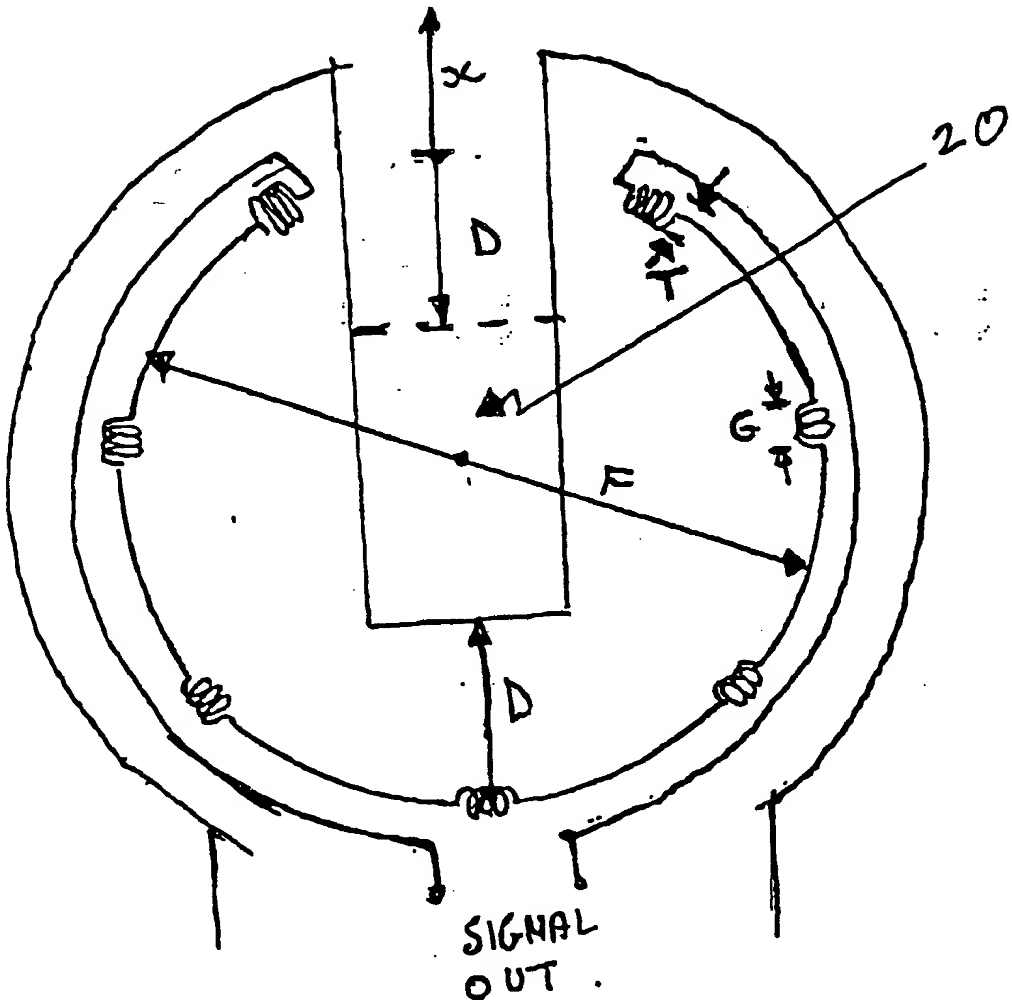

FIG. 3

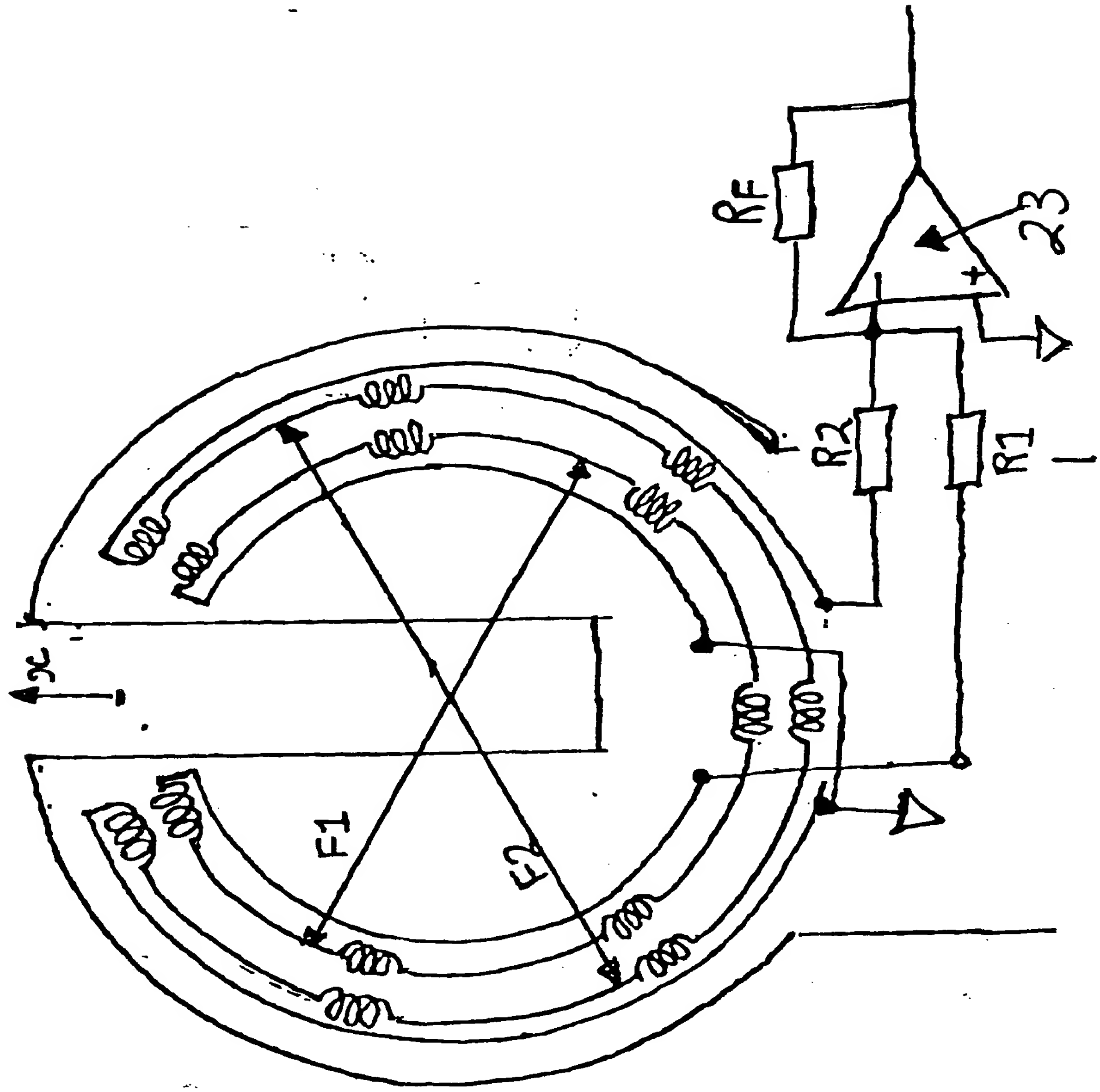

FIG. 4